Ocean Acoustics and Signal Processing for Robust Detection and Estimation

Zoi-Heleni Michalopoulou
Department of Mathematical Sciences
New Jersey Institute of Technology
Newark, NJ 07102
phone: (973) 596 8395 Fax: (973) 596 5591 E-mail: michalop@njit.edu

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URL: http://www.math.njit.edu/~elmich

LONG TERM GOALS

The long term goal of this project is to develop efficient inversion algorithms for successful estimation and detection by incorporating (fully or partially) the physics of the propagation medium. Algorithms will be designed for robust ASW localization and detection and also for geoacoustic inversion.

OBJECTIVES

- Achieve accurate and computationally efficient source localization by designing estimation schemes that combine acoustic field modeling and optimization approaches.

- Develop methods for passive localization and inversion of environmental parameters that select features of propagation that are essential to model for accurate inversion.

APPROACH

A high-resolution time delay estimation method was developed, that is suitable for underwater propagation environments with an unknown number of arrivals reaching the receiver. The time delay estimates obtained with this method were related to source location, array element positions, and bottom depth through a linearized system of equations; the coefficient matrix of the system consists of derivatives of arrival times with respect to the unknowns. The system was regularized using prior information for stabilization of the solutions.

Classical matched-field processing methods were revisited; the importance of source spectrum and noise variance estimation in obtaining “sharper” ambiguity surfaces was investigated.

WORK COMPLETED

The Gibbs Sampling time delay estimation algorithm the PI has developed [1] was further tested and evaluated. The algorithm’s efficiency was improved by including the number of multipaths as one of the unknown parameters in the estimation process (instead of obtaining estimates of time delays for many different arrival numbers and keeping the best set of results, we treated the arrival number as an unknown quantity with its own prior distribution and inverted for it). The modified algorithm was

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14. ABSTRACT
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15. SUBJECT TERMS

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applied to the Haro Strait data set for source localization, array element localization, and estimation of the water column depth. The method and results are presented in [2].

In addition, a matched-field processing method was developed and tested on synthetic data. The method relies on first forming the joint posterior probability distribution of source range and depth (and, potentially, uncertain environmental parameters), source amplitude and phase, and noise variance. The marginal distribution of source range and depth can be then obtained by integrating the joint multivariate distribution over source phase and amplitude and noise variance. The new approach treats source characteristics and noise (and, in consequence, signal to noise ratio) as unknown parameters with their own statistical descriptions. In contrast, classic (Bartlett) matched field processing uses a maximum likelihood estimate of the source amplitude and phase as well as noise variance in order to formulate an estimator (ambiguity surface) for source range and depth [3].

RESULTS

The time-delay estimation method was modified this time to incorporate the number of arrivals M as an unknown in the actual estimation stage. That is, a conditional distribution of M on amplitudes and delays was identified, and samples from this distribution were drawn during the Gibbs sampling process. The estimator was then applied to data collected during the Haro Strait primer experiment [4].

Estimates of time delays and amplitudes of several multipaths were obtained for time series recorded at three vertical line arrays; delays were subsequently used for source localization, array element localization, and bottom depth estimation. Estimation was performed by setting up a system relating unknowns to arrival times in an approximately linear fashion. Because of ill-conditioning of the coefficient matrix **J** of the linear system (a Jacobian matrix containing derivatives of arrival times with respect to unknowns), the system was regularized by adding weighted prior information. The prior weights were determined through an L-curve analysis [5].

Estimates obtained with the method outlined above were very close to reference values for source location and bottom depth. Detailed inversion for array element position was achieved as well. Table I shows results for source range (from top receiving phone), source depth, and water column depth estimated from data recorded at one of the arrays deployed for the experiment. The estimates match very well the reference values provided for source location and site bathymetry.

The robustness of the approach was tested by applying the processor to several data sets collected during the experiment and comparing the results. Figure 1 shows array element localization estimates obtained from receptions corresponding to two different sources. The receiving array and the two sources were located on an approximately straight line. The results of Figure 1 show that the array shapes, as “seen” by the two sources, are almost identical (as expected because of the source positions) demonstrating the consistency of the method.

Table I: Estimates of source range and depth and water column depth.

parameter	estimate	Reference
r_1 (m)	1332.2	1348.9
z_s (m)	50.5	50.0
D (m)	195.1	190.0

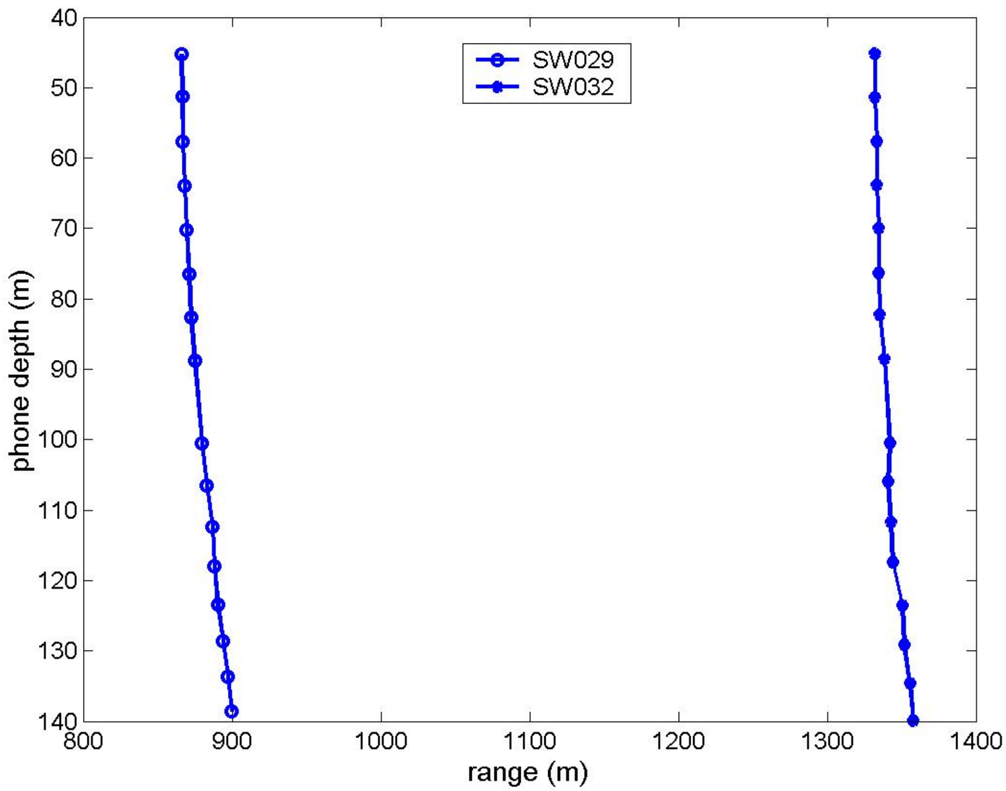

Figure 1: Array element localization with data from two different sources; the two sources and the receiving array were all located on the same line.

On matched-field processing using source spectrum information, source localization was evaluated at different noise levels using the proposed processor and a conventional Bartlett estimator. Figure 2 shows probability of correct localization for the two processors vs. noise variance for a frequency of 600 Hz. There is a clear improvement in localization performance with the proposed processing scheme, especially as noise level increases.

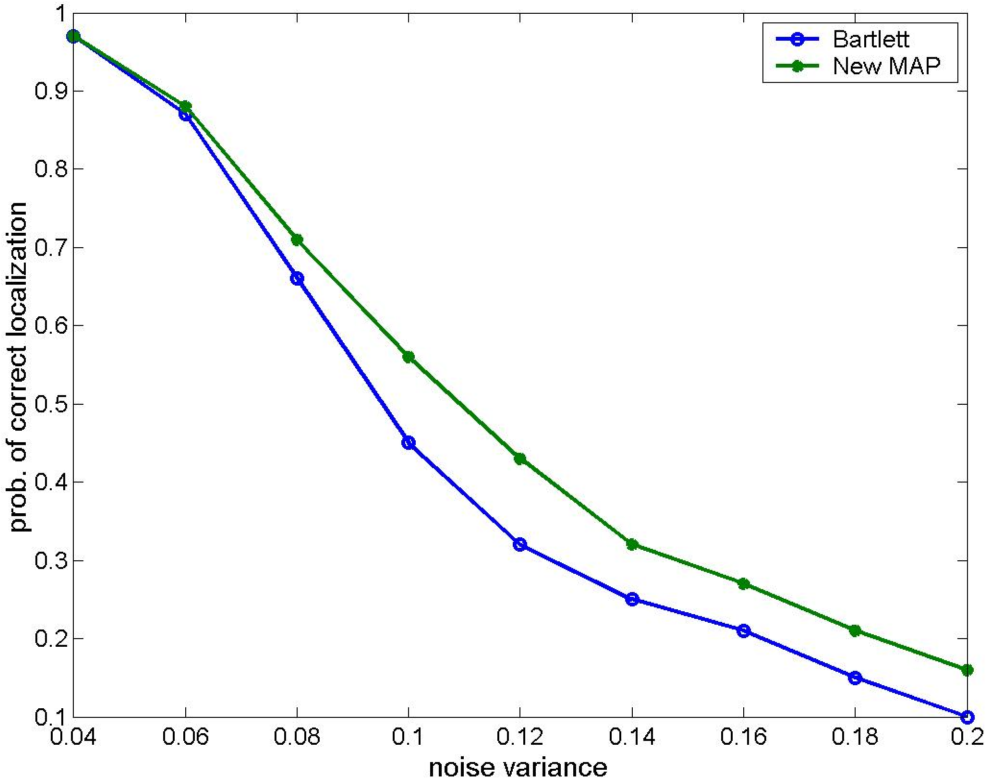

Figure 2: Probability of correct localization from simple Bartlett processing (blue) and processing including the estimation process source amplitude and phase.

IMPACT

Tomography and several inversion approaches (for localization or environmental parameters) rely on time delays and amplitudes of distinct arrivals; these have to be accurately estimated for the inversion to provide meaningful and reliable results.
The Gibbs Sampling arrival time and amplitude estimation method is a robust tool for this task, without requiring excessive computations and was shown to work successfully with real data. In particular, the combination of the time delay estimator with a simple multipath model gave excellent localization results for a challenging data set.

In addition to localization results that can be readily obtained by using the delay estimates made available from the Gibbs Sampler, environmental information can be extracted from the amplitude estimates that are also produced.

The proposed modification to matched-field processing improves source localization, with the improvement being more visible as the signal to noise ratio drops. This is an important finding, giving the proposed method an advantage in localization of quiet sources. The method is also expected to perform well in geoacoustic inversion as well.

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